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Australian Government

Department of Defence

Defence Science and Technology Group



# A numerical investigation on the response of thick ultra-high molecular weight polyethylene composite to ballistic impact

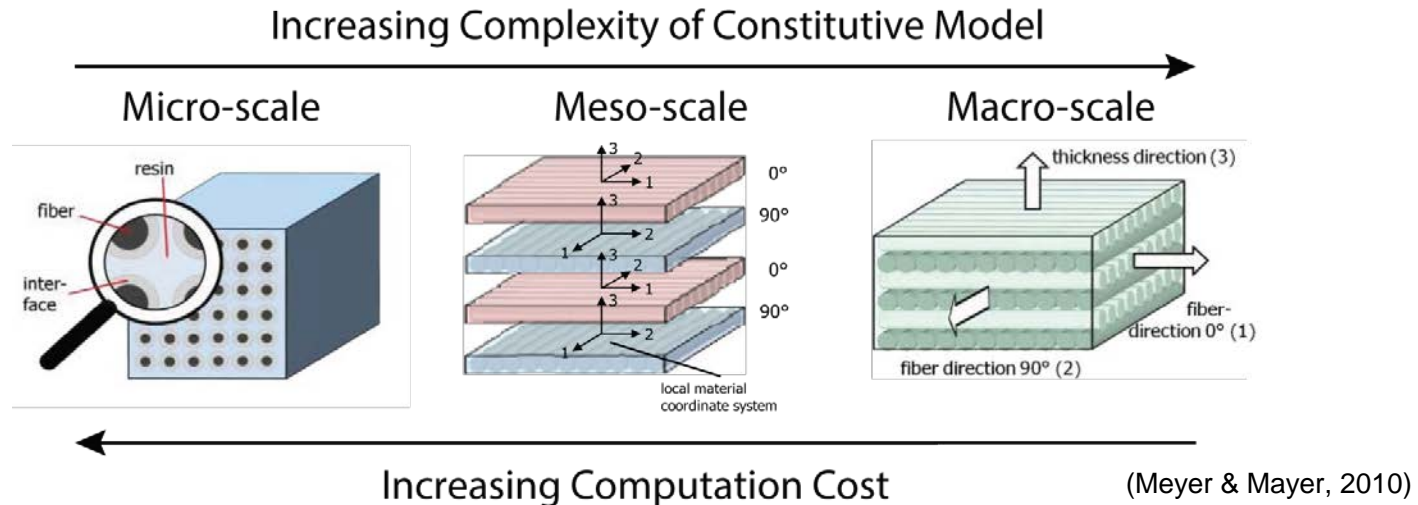
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<sup>2</sup> RMIT University

29<sup>th</sup> International Symposium on Ballistics

# Numerical Modelling Approach



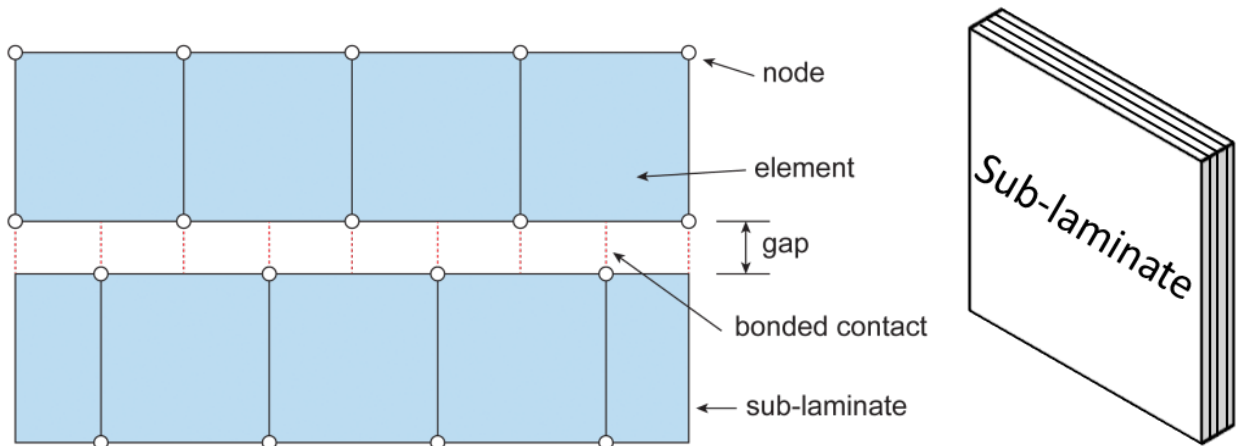
- Aim: model thick targets
  - Continuum model (100 mm thick panel has ~1600 plies)
- Non-linear orthotropic continuum model
  - Non-linear EoS
  - Non-linear orthotropic strength model
  - Interactive orthotropic failure

# Accounting for Severe Strength Anisotropy

- Modified Hashin failure :

$$\left(\frac{\sigma_{ii}}{S_{ii}(1-D_{ii})}\right)^2 + \left(\frac{\sigma_{jj}}{S_{jj}(1-D_{jj})}\right)^2 + \left(\frac{\sigma_{kk}}{S_{kk}(1-D_{kk})}\right)^2 \geq 1 \quad \text{for } i, j, k = 1, 2, 3$$

- Failure in one direction initiates softening in others
- Sub-laminate discretization implemented

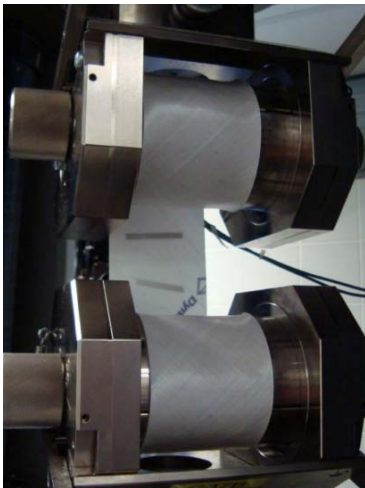


Bond failure:

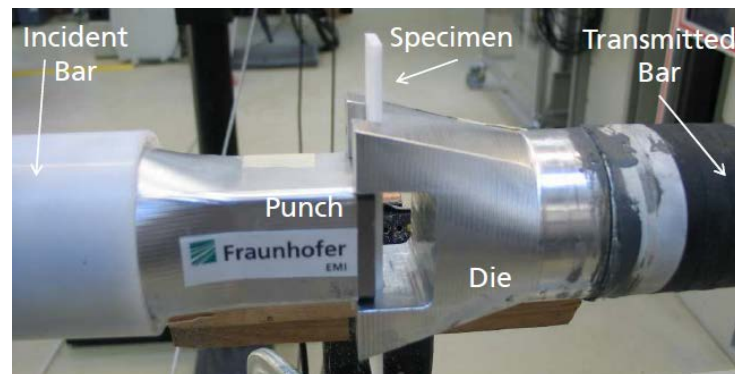
$$\left(\frac{\sigma_N}{S_N}\right)^a + \left(\frac{\sigma_S}{S_S}\right)^b \geq 1$$

# Constitutive Model Parameters

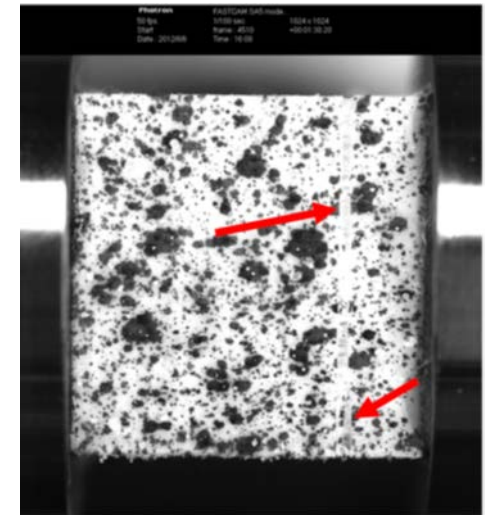
- Mix of quasi-static and dynamic testing
  - Performed in collaboration with Fraunhofer EMI & DSM



Quasi-static in-plane tension



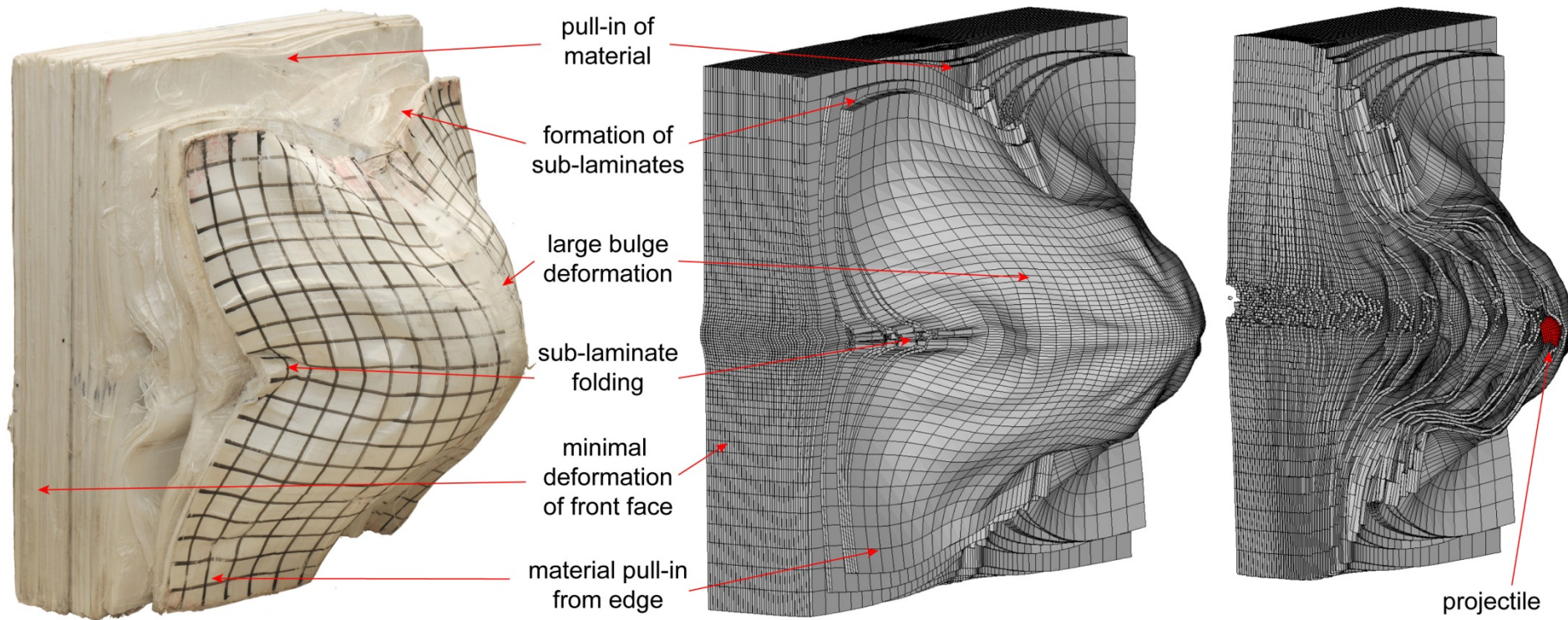
Dynamic out-of-plane shear



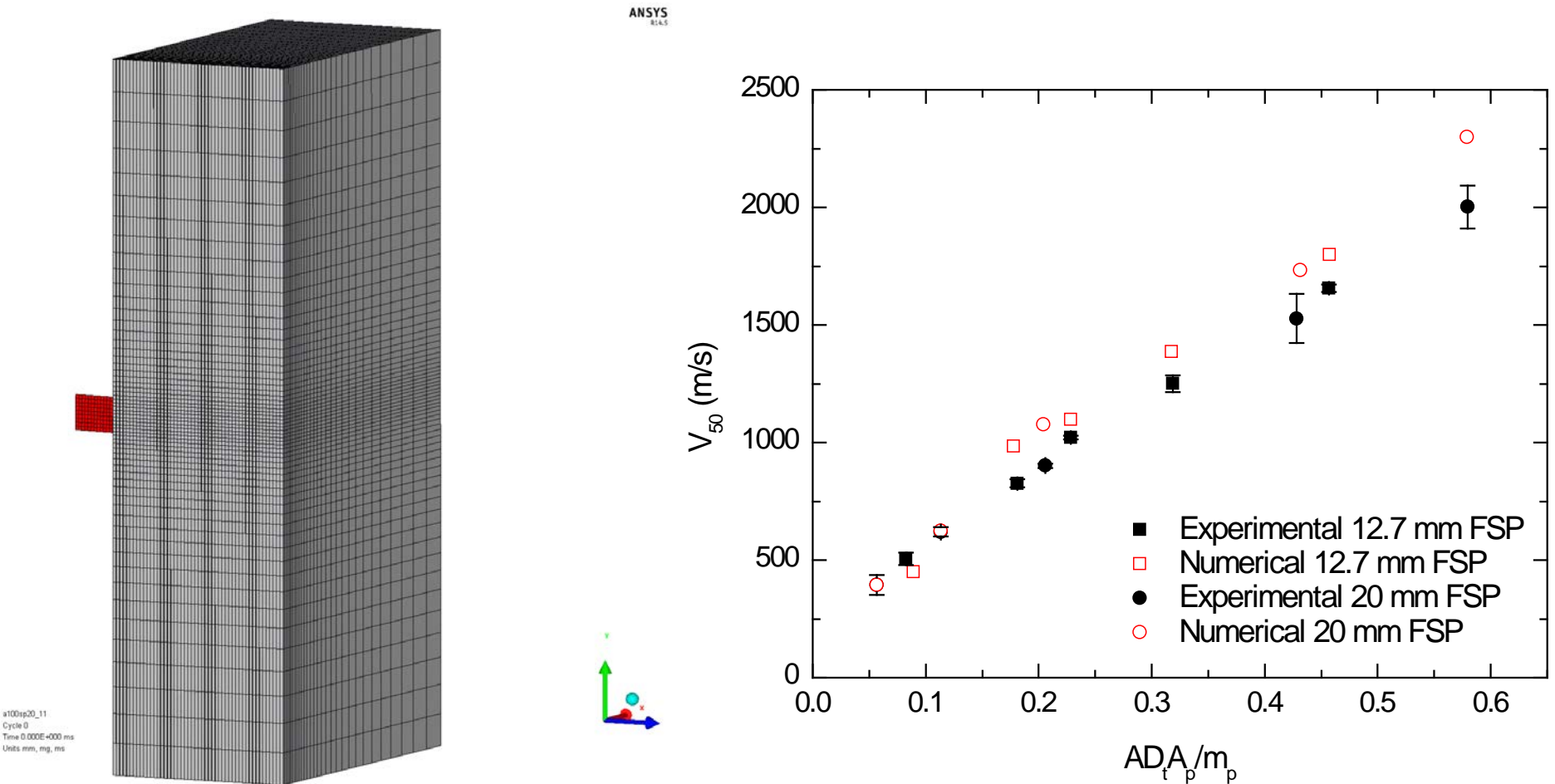
Quasi-static out-of-plane tension

# Qualitative Assessment

- The model is able to capture key characteristics of UHMW-PE composite under ballistic impact

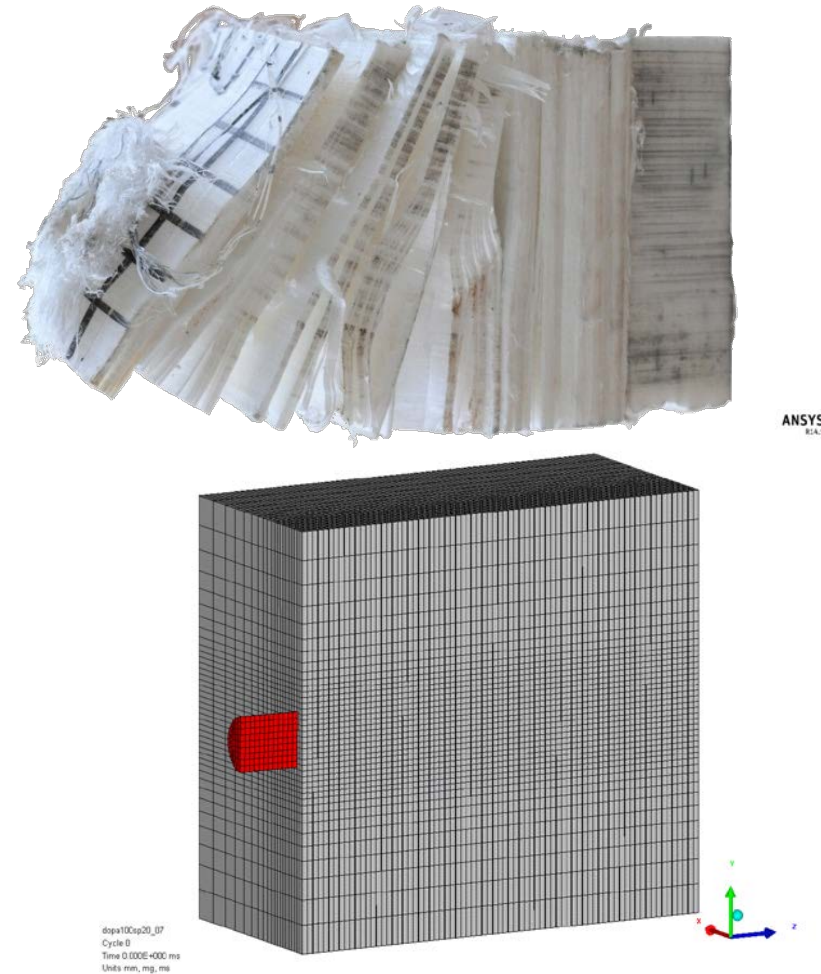
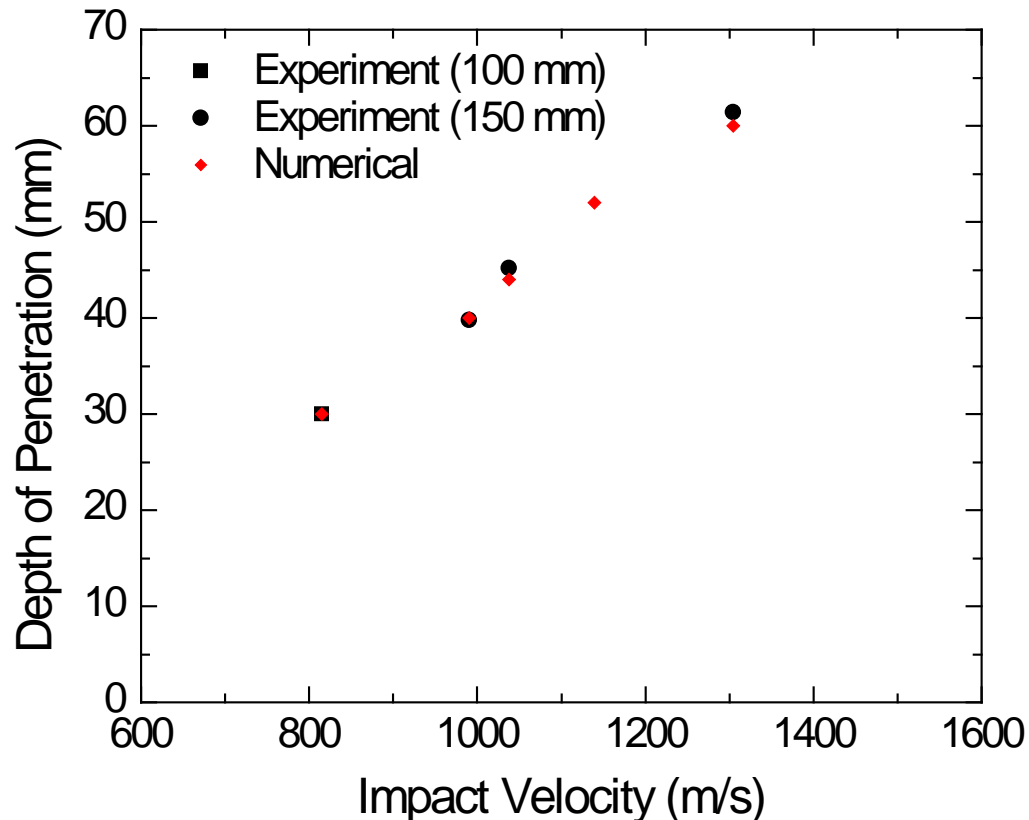


# Quantitative Assessment – Finite Target $V_{50}$



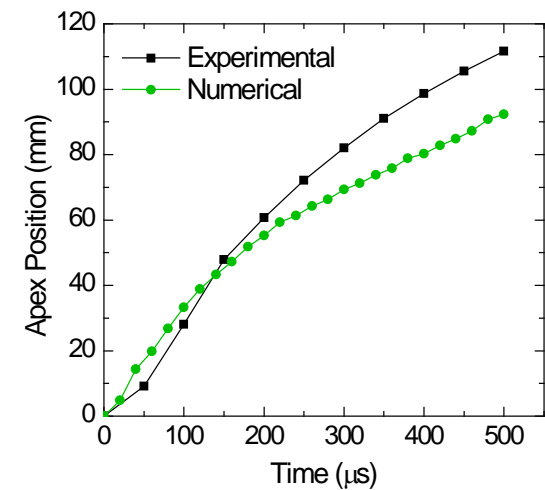
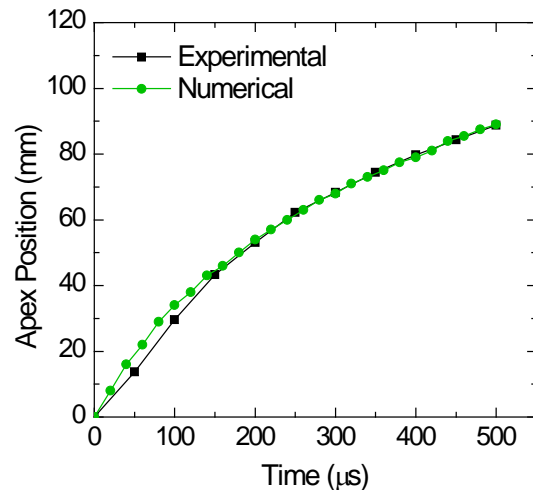
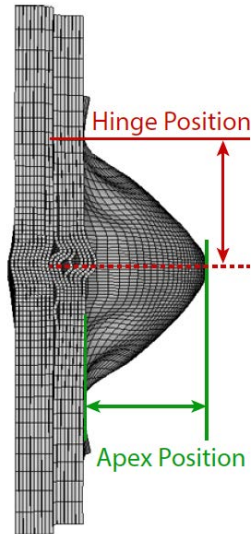
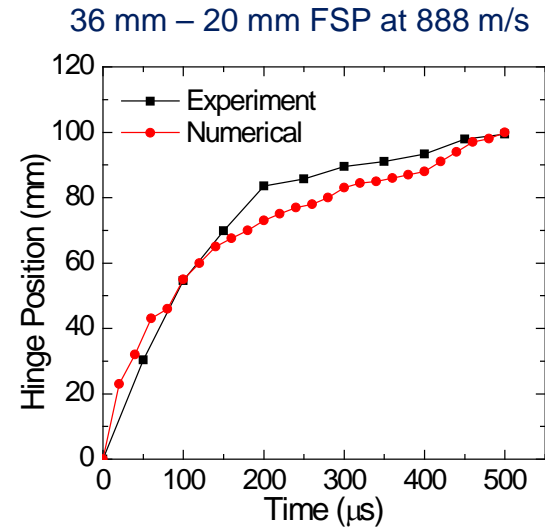
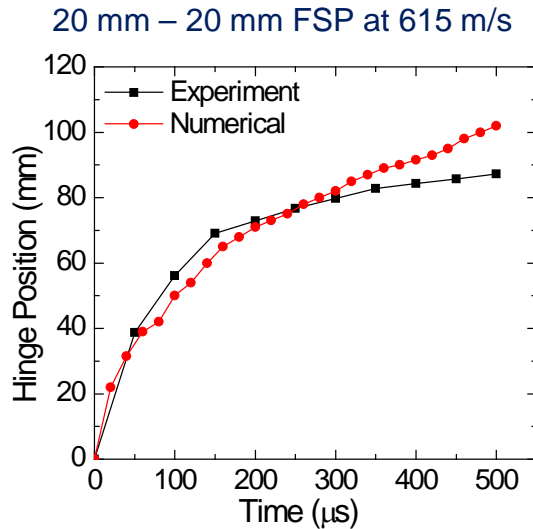
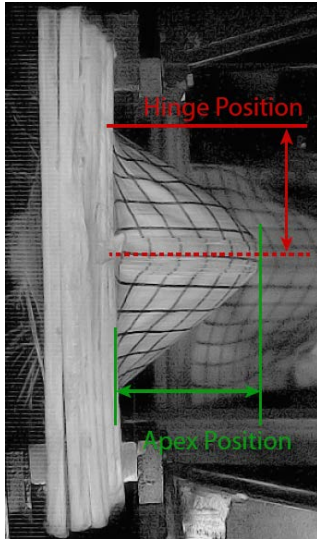
Numerical predictions are within 20% of experimental  $V_{50}$

# Quantitative Assessment – Semi-infinite DoP



Numerical predictions are within 5% of experimental DoP

# Quantitative Assessment – Bulge Formation

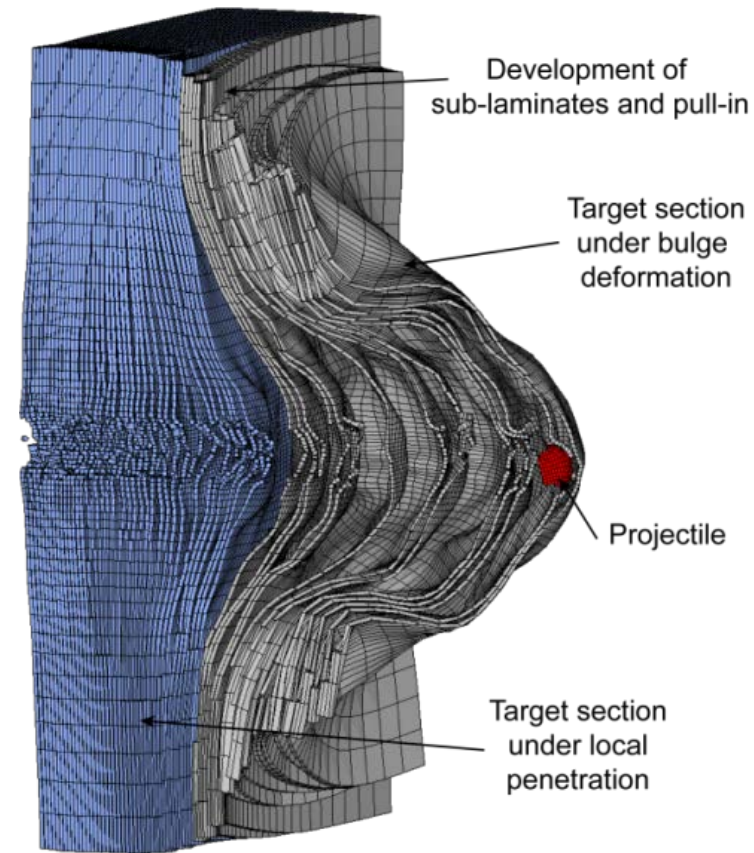
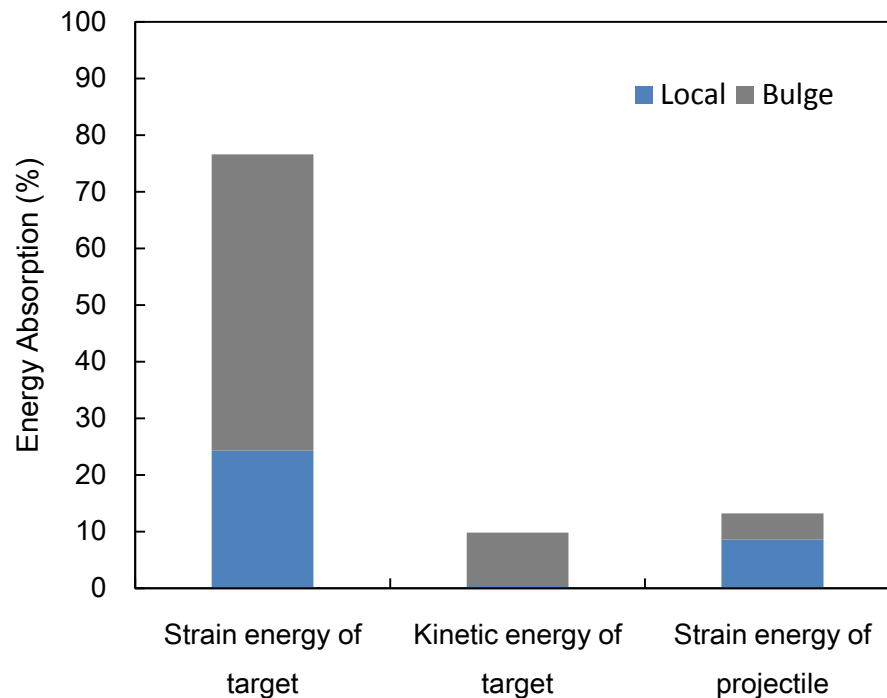


# Exploitation of the Numerical Model

- Model validated for penetrator class (i.e. FSP)
- Can now be exploited to:
  - Better understand failure mechanisms
  - Investigate the influence of changing properties
  - Aid in designing the next generation of materials
  - Reduce experimental burden
  - Optimize design in multi-material armour configurations

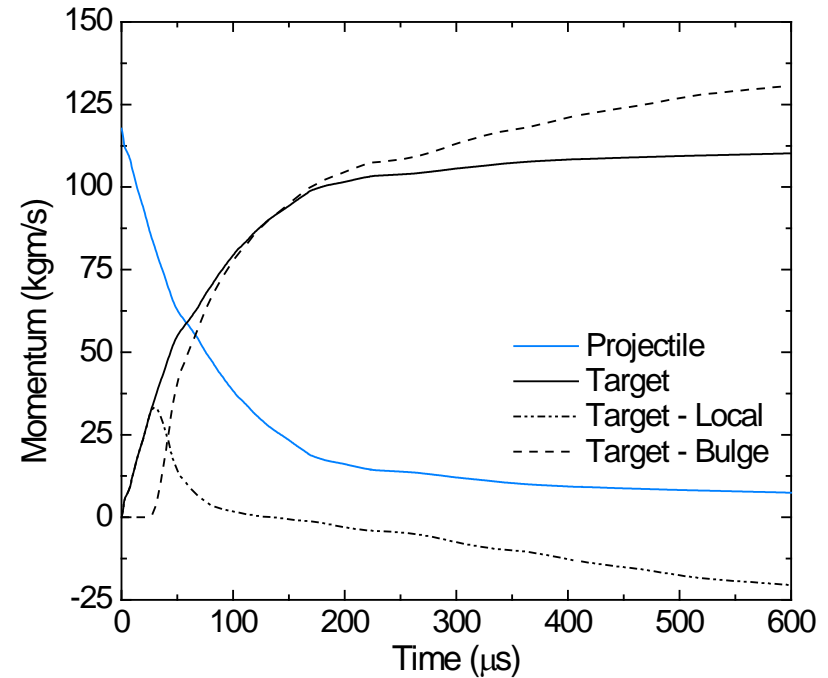
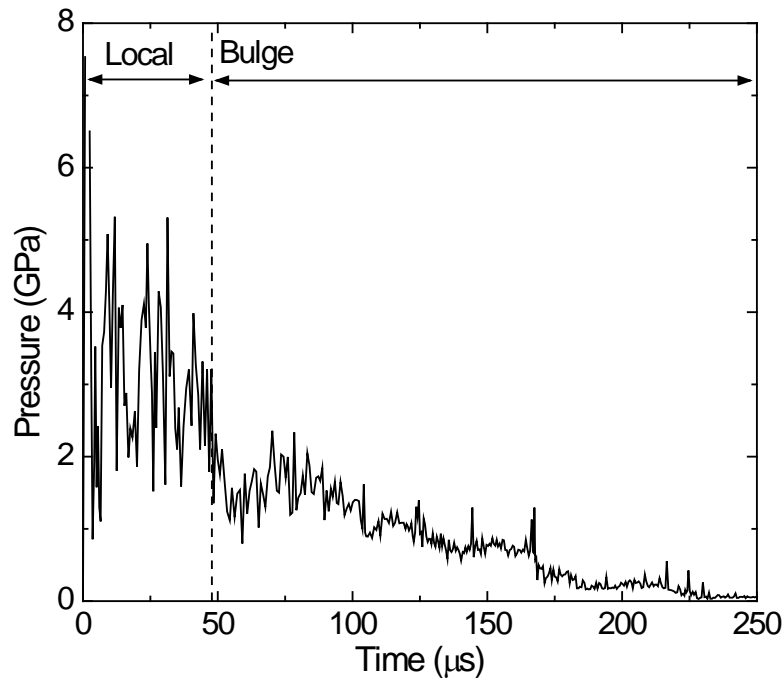
# Penetration Resistance

- Two stages of penetration
  - Localised: low energy absorption
  - Bulging: high energy absorption

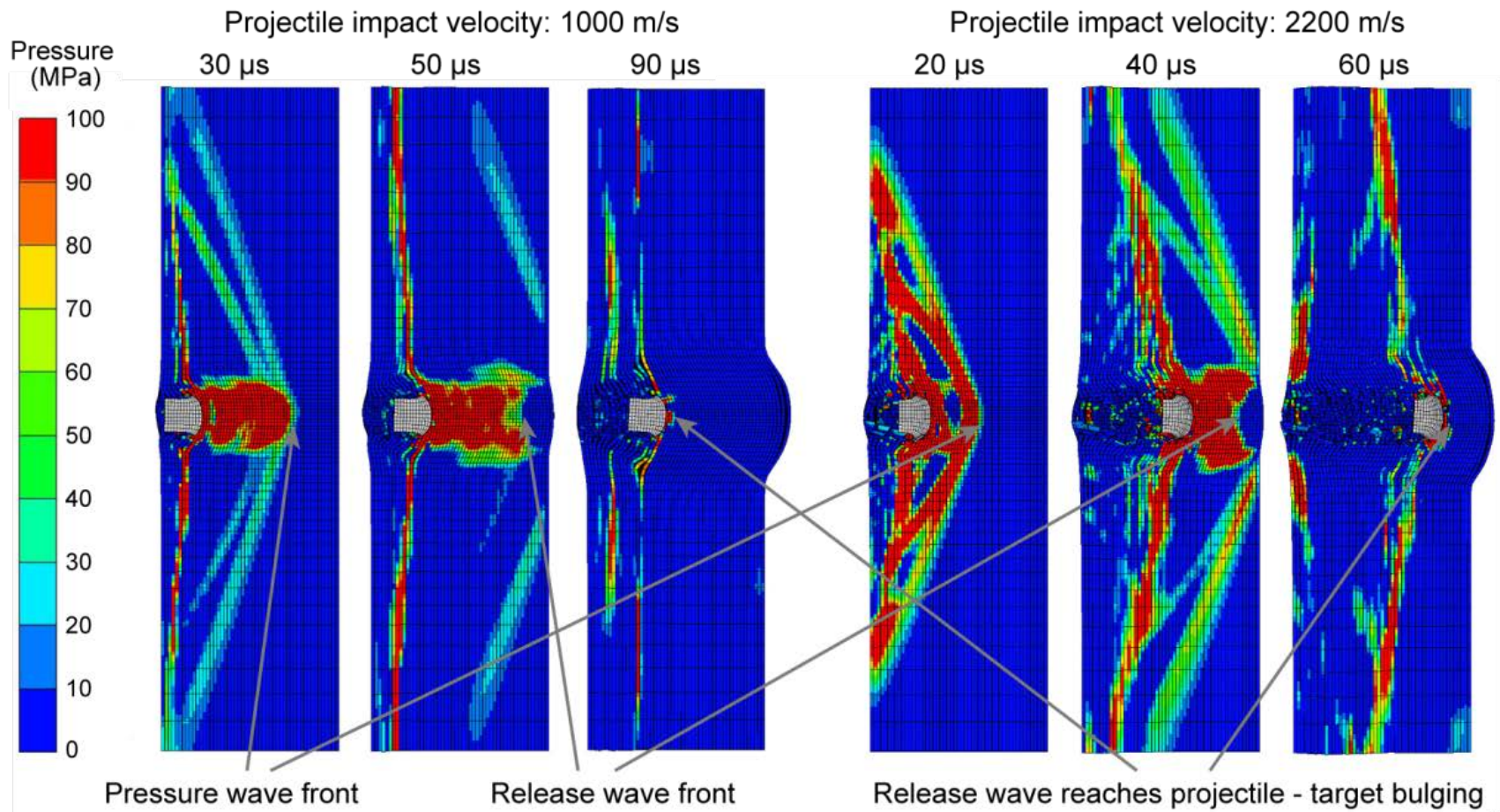


## Penetration Resistance (cont.)

- Two stages of penetration
  - Localised: High pressure, low momentum transfer
  - Bulging: low pressure, high momentum transfer

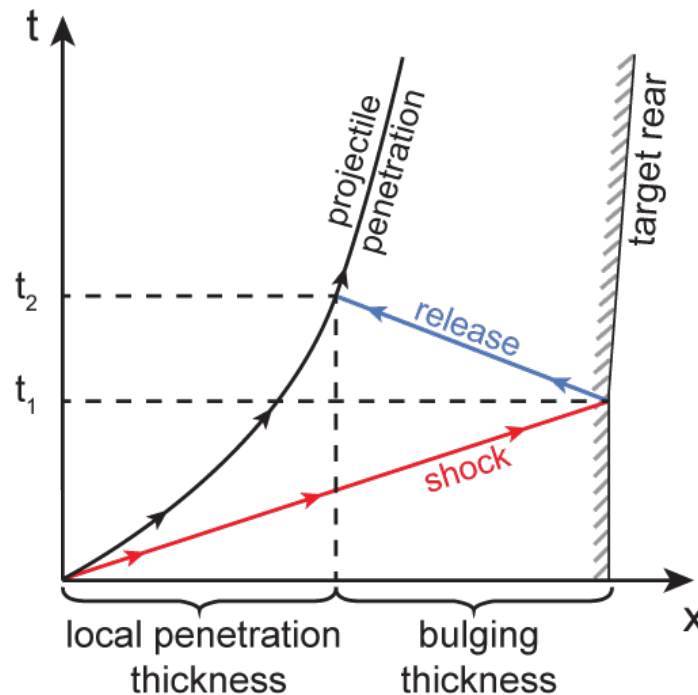


# Transition of Penetration Mechanisms

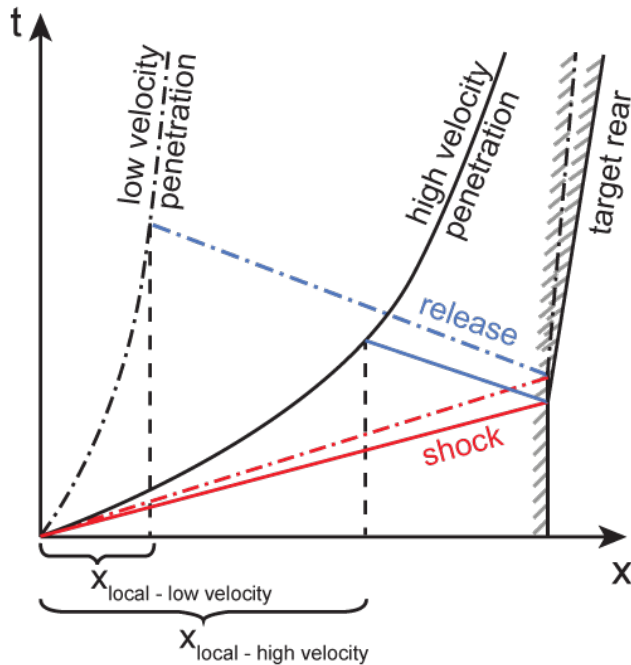


# Transition

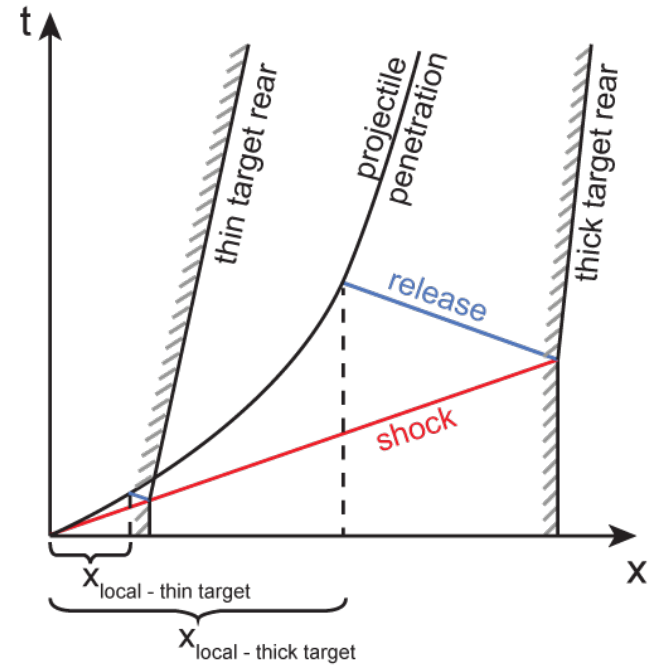
- Transition to bulging is driven by:
  - Impact velocity
  - Shock and release properties of the material



# Influence of Impact Conditions



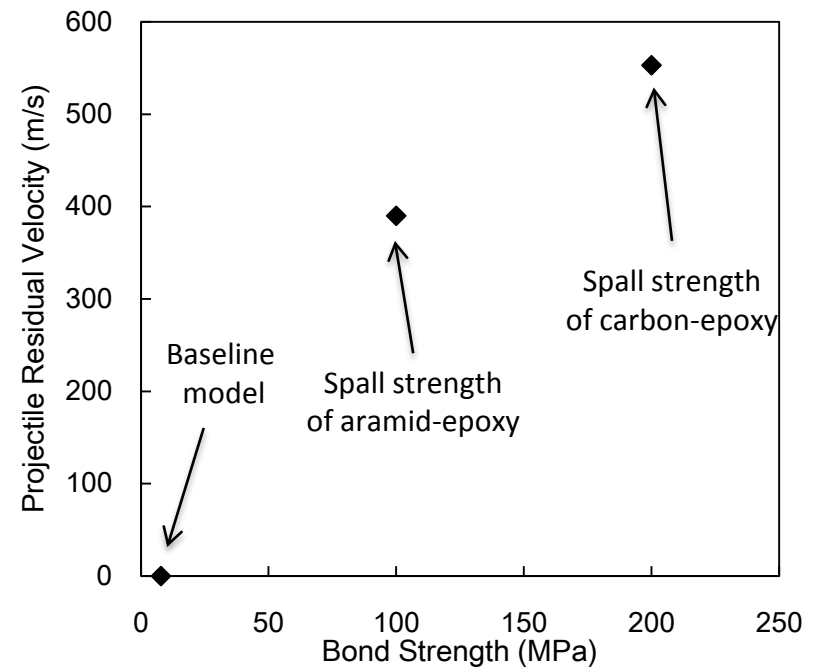
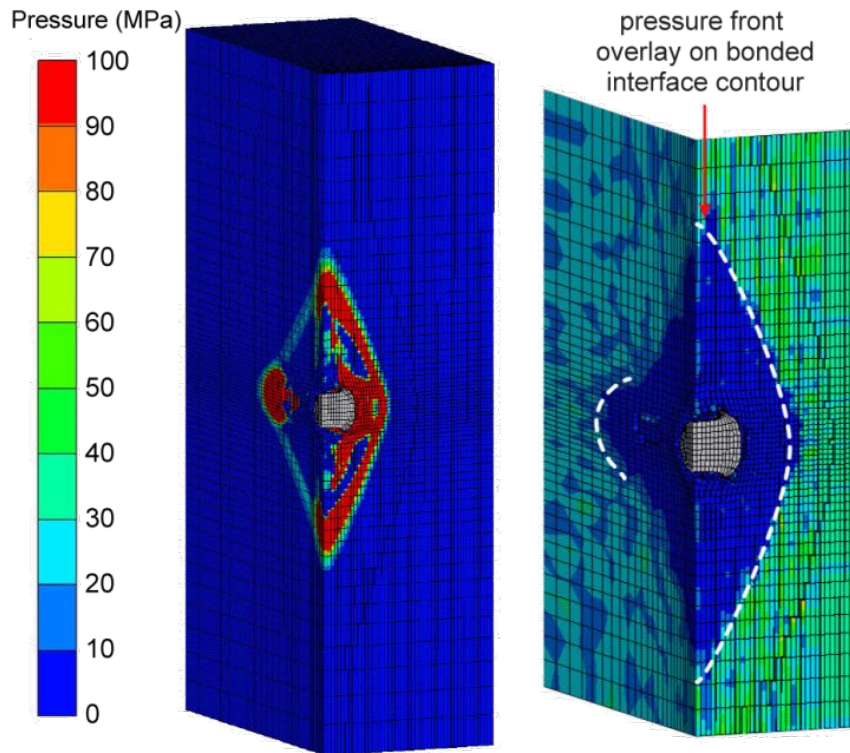
↑ Impact velocity  
 ↓ Proportion under bulging



↑ Target thickness  
 ↑ Proportion under bulging

# Delamination

- Impact shock induced delamination
- Allows material to deform, absorbing more energy
- Increased interlaminar strength → decrease performance



102 mm thick HB26 impacted by 20 mm FSP at 2200 m/s

## Conclusion

- Thick laminates of UHMW-PE composite exhibit two-stage penetration under ballistic impact
- Bulging is significantly more effective than local penetration
- Transition to bulging is influenced by the stress wave properties of the material and the projectile penetration rate
- Delamination occurs ahead of the projectile and is important in allowing the target to exhibit extensive bulging – driven by the pressure wave